PASPALUM PUBIFLORUM AND *P. QUADRIFARIUM* (POACEAE) NEW TO CALIFORNIA, WITH A KEY AND NOTES ON INVASIVE SPECIES

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ABSTRACT

Paspalum pubiflorum and *P. quadrifarium* are reported for the first time for California. New records are also documented for *P. vaginatum*, which is invasive in estuarine wetland habitats. We summarize the current naturalized status, habitats occupied, and regions where recently introduced species of *Paspalum* have been observed or might become invasive in California. We also provide a key to the identification of *Paspalum* species known to occur in the State.

Key Words: California, estuarine wetlands, invasive grasses, nonnative plants, *Paspalum*

RESUMEN

Las especies *Paspalum pubiflorum* y *P. quadrifarium* se reportan por primera vez en California. También se han documentado nuevos registros de *P. vaginatum* que es una especie invasora de los hábitats de humedales estuarinos. Resumimos la situación actual de naturalización, los hábitats ocupados y las regiones donde se ha observado la introducción reciente de especies de *Paspalum* o pudieran convertirse en invasoras en California. También proporcionamos una clave para la identificación de las especies de *Paspalum* que se sabe que ocurren en el estado.

INTRODUCTION

Paspalum L. (Poaceae, Panicoideae) is comprised of approximately 350 species, which are distributed primarily in the subtropical, tropical, and warm-temperate regions of the Americas (Zuloaga & Morrone 2005; Denham et al. 2010). However, owing to their utility as turf, forage or ornamental grasses, many taxa are now widely distributed and have become some of the world's most troublesome weeds (Holm et al. 1979; Weber 2003; GCW 2010; PIER 2010).

The genus *Paspalum*, in general, is easily recognized by its unilateral racemes distributed along the main axis of the inflorescence, plano-convex spikelets with the upper lemma oriented towards the rachis, and the lower glume typically being absent. Confident, species-level determinations, however, often prove difficult. Comparative ecological studies, such as growth responses to salinity and soil saturation, and vegetative morphology, phenology, and habitat associations can improve separation and help explain species distribution (Lakanmi & Okusanya 1990; Rua et al. 2008). Many species of *Paspalum* are also weedy, and since weeds are generally under-collected and thus poorly represented in herbaria, the distribution of many nonnative taxa in North America is poorly known (Allen & Hall 2003). *Paspalum vaginatum* Sw. (seashore paspalum), native to the subtropical and tropical regions of the New World, has been introduced widely and is now naturalized in warm, coastal regions around the world (Allen & Hall 2003; Weber 2003; Zuloaga et al. 2003). Naturalized populations were reported for the first time for California by Riefner and Columbus (2008).

In this paper, we provide the first documented records of *P. pubiflorum* Rupr. ex E. Fourn. and *P. quadrifarium* Lam. for California; *P. pubiflorum* was collected from Orange and western Riverside counties, and *P. quadrifarium* from Los Angeles County in southern California. New records are also documented for *P. vaginatum*, which is invading estuarine and other saline wetlands in southern California. We review the naturalized status, habitats occupied, mode of introduction, and provide a summary of the regions in California where recently introduced species of *Paspalum* have been observed or might become invasive. A key is also provided to identify the known species of *Paspalum* in the State.

NEW RECORDS FOR CALIFORNIA

Paspalum pubiflorum (hairyseed paspalum) and *P. quadrifarium* (tussock paspalum) have not been reported previously for California in treatments of the nonnative Poaceae growing outside of cultivation (Hitchcock 1951; Webster 1993; Bossard et al. 2000, 2006; Hrusa et al. 2002; Allen & Hall 2003; DiTomaso & Healy 2003, 2007; Roberts et al. 2004; Rebman & Simpson 2006; Bossard & Randall 2007; Clarke et al. 2007; Grewell et al. 2007; Riefner & Boyd 2007; Dean et al. 2008; Roberts 2008; Jepson Flora Project 2010; USDA 2010a, b).

Paspalum pubiflorum Rupr. ex E. Fourn.

Voucher specimens: **U.S.A. CALIFORNIA. Orange Co.:** City of Yorba Linda, Santa Ana Canyon, N bank of Santa Ana River, vicinity of La Palma Ave. and Via Lomas De Yorba East, UTM (NAD 83) 11S 043306E 3748143N, elev. ca. 110 m, locally common in mud among rocks and in shallow water, 30 Sep 2007, *Riefner 07-419* (RSA, SI); City of Yorba Linda, Santa Ana Canyon, N bank of Santa Ana River, E of Weir Canyon Rd., vicinity of La Palma Ave. and Mercado del Rio, UTM (NAD 83) 11S 0431111E 3748960N, elev. ca. 107 m, locally common on banks and in shallow water, 2 Dec 2007, *Riefner 07-503* (RSA, SI), same locality, 10 Oct 2009, *Riefner 09-222* (RSA); City of Mission Viejo, Oso Creek, ca. 1.4 mi N of Paseo De Colinas on Camino Capistrano, UTM (NAD 83) 11S 0437526E 3715062N, elev. ca. 88 m, rare, growing with *Paspalum distichum*, small clump in rip-rap rocks and in shallow water near a waste water treatment plant, 11 Nov 2009, *Riefner 09-237* (RSA). **Riverside Co.:** City of Corona, Santa Ana Canyon, Santa Ana River below Prado Dam, ca. 0.5 mi SW of 71 Fwy., UTM (NAD 83) 11S 0438734E 3749611N, elev. ca. 135 m, uncommon, on banks and in shallow water, 10 Oct 2009, *Riefner 09-225* (RSA).

Paspalum pubiflorum is a perennial grass native to the eastern and southwestern United States (Pennsylvania to Texas and Colorado), Mexico, and Cuba (Allen & Hall 2003; Denham et al. 2010; USDA 2010a). In the United States, it grows on moist open ground and disturbed areas, in wet meadows, on banks and edges of forests, streams, ponds, lakes, and irrigation ditches, especially in alkaline or calcareous soils (Hitchcock 1951; Correll & Correll 1975; Allen & Hall 2003).

Paspalum pubiflorum has branched decumbent culms that frequently root at the nodes (Fig. 1a). It has (2–)3–12 racemes per inflorescence with pubescent, rarely glabrescent or glabrous paired spikelets, which are elliptic to obovate-elliptic and (2.4–)2.6–3.2 mm long (Denham et al. 2010). The number of racemes per inflorescence is not a fixed character and varies considerably; Hitchcock (1951) reports 3–5 racemes, and Allen and Hall (2003) report 2–7 racemes per inflorescence. In southern California, populations typically have 3–6 racemes per inflorescence, but it is not uncommon to find plants having 2–3 racemes per inflorescence (Fig. 1b). *Paspalum hartwegianum* E. Fourn. (Hartweg's paspalum) is similar to *P. pubiflorum*. It has simple erect culms with 3–23 racemes (also highly variable) per inflorescence, and paired pubescent spikelets, which are elliptic to obovate and (2.3–)2.6–3.1 mm long (Denham et al. 2010). Accordingly, careful collecting and documentation in the field is needed to accurately separate *P. pubiflorum* from *P. hartwegianum* and other closely related species; currently, *P. hartwegianum* is not known to occur in California.

In southern California, *P. pubiflorum* could be confused with robust forms of *P. distichum* L. (knotgrass), which is a native rhizomatous or stoloniferous perennial with spikelets pubescent only on the back of the upper glumes. Its inflorescence is digitate (with two branches), but a third lower branch may occasionally be present. *Paspalum distichum* is a highly variable species; it can be slender and creeping or robust and cespitose. Although *P. distichum* usually has solitary spikelets, racemes with only paired spikelets or racemes with paired and solitary spikelets can be present on the same plant. Robust forms of *P. distichum* with mostly 3 racemes per inflorescence and paired spikelets collected in southern California have been called *Paspalum*

Fig. 1a. *Paspalum pubiflorum* has branched decumbent culms that frequently root at the nodes. It can form locally dense mats that compete for space with native hydrophytes on stream and river banks. Photograph taken in October, 2008, Santa Ana Canyon, Santa Ana River, Orange County, California.

Fig. 1b. The southern California populations of *Paspalum pubiflorum* may have 2–3 racemes per inflorescence, which could be easily mistaken in the field for *Paspalum distichum*. Photograph taken in July, 2008, Santa Ana Canyon, Santa Ana River, Orange County, California.

paucispicatum Vasey (Hitchcock 1951). *Paspalum paucispicatum* (a synonym of *P. distichum*; Zuloaga et al. 2003) has often been confused with *P. pubiflorum* (Verloove & Reynders 2007a).

Paspalum pubiflorum can be weedy when introduced to new regions (GCW 2009). In southern California, it can form dense mats that compete for space with low-growing native hydrophytes in riverine and urban creek habitats. Although *P. pubiflorum* occupies alkaline habitats, and unlike *P. distichum* and *P. vaginatum*, which are known halophytes (Menzel & Lieth 2003), it is not expected to successfully colonize highly saline estuarine wetlands in southern California.

Paspalum pubiflorum is not utilized for turf, so its occurrence in California is probably the result of an accidental introduction. Its dispersal, invasive behavior, and naturalized distribution require further field study and documentation. Because it can be confused with *P. distichum*, it is likely more widespread than our records indicate.

Paspalum quadrifarium Lam.

Voucher specimen: **U.S.A. CALIFORNIA. Los Angeles Co.:** City of San Dimas, Puddingstone Reservoir, Bonelli Regional Park, East Shore Dr., UTM (NAD 83) 11S 0426136E 3771937N, elev. ca. 285 m, rare, outer flood zone along sunny edge of sandy riparian scrub, 1 Jul 2007, *Riefner 07-288* (RSA, SI).

Paspalum quadrifarium is a large cespitose perennial native to Argentina, Brazil, Paraguay, and Uruguay (Allen & Hall 2003; Zuloaga et al. 2003). In Argentina, *P. quadrifarium* forms dense tussocks in the Flooding Pampa grasslands, on river banks or lake shores, and is often regarded as a weed (Ortega & Laterra 2003; Herrera et al. 2005).

Paspalum quadrifarium is grown as an ornamental in Florida, and has escaped cultivation in the southeastern states (Garbari 1972; Allen & Hall 2003; USDA 2010b). It has been identified as a noxious weed or is a potential invasive pest in New South Wales and Queensland, Australia, coastal Italy, and the southern United States (Allen & Hall 2003; Verloove & Reynders 2007b; Bargeron et al. 2008; Sydney Weeds Committees 2010).

In southern California, *P. quadrifarium* most likely escaped from cultivated sources, and currently is known only from a small population growing in disturbed riparian scrub. Accordingly, this species is here considered tenuously established and its dispersal and naturalization remains to be studied and documented.

Paspalum vaginatum Sw.

Voucher specimens: **U.S.A. CALIFORNIA. Orange Co.:** City of Dana Point, near Ritz-Carlton Hotel, Salt Creek Beach area, UTM (NAD 83) 11S 0432734E 3704750N, elev. ca. 1–2 m, local on the coastal strand, 29 Jul 2008, *Riefner 08-256* (RSA); City of Dana Point, near Ritz-Carlton Hotel, Salt Creek Beach area, UTM (NAD 83) 11S 0432950E 37074260N, elev. sea level, local in wet beach sand within the high tide zone, 29 Jul 2008, *Riefner 08-257* (RSA); City of Irvine, tidal portion of San Diego Creek at Hwy. 73 overpass, UTM (NAD 83) 11S 0420350E 3723837N, elev. ca. 1 m, common and invasive on sandy flats, creek banks, and brackish marsh, 31 Aug 2008, *Riefner 08-267 & Campbell* (RSA); City of Newport Beach, Upper Newport Bay, Delhi Channel near University Dr., UTM (NAD 83) 11S 0418062E 3724031N, elev. sea level, local, muddy banks and flats along tidal channel, 2 Jan 2009, *Riefner 09-10* (RSA). **Riverside Co.:** Sonoran Desert region, Cathedral City, drainage tributary to Whitewater River, Perez Rd. at Date Palm Dr., UTM (NAD 83) 11S 0550217E 3737981N, elev. ca. 82 m, uncommon in wet sand along slow-moving waters of urban creek, 5 Jul 2008, *Riefner 08-215* (RSA). **San Diego Co.:** City of Oceanside, tidal portion of San Luis Rey River at Interstate-5 overpass, UTM (NAD 83) 11S 0464168E 3674334N, elev. ca. 1–2 m, locally invasive on sand flats and in brackish marsh, 15 Sep 2008, *Riefner 08-288* (RSA).

Paspalum vaginatum is known from warm temperate, tropical, and subtropical regions around the world, and is widely regarded as an invasive species; see Erickson and Puttock (2006), ISSG (2008), and Riefner and Columbus (2008) for reviews. Worldwide, and outside of cultivation, *P. vaginatum* occupies coastal salt and brackish water marshes, shallow-water lagoons and tidal channels, mangroves, coastal shrublands, dunes and beaches, summer-moist saltpans, wet pastures, and freshwater riparian and floodplain habitats (Allen & Hall 2003; Shaw & Allen 2003; Weber 2003; Siemens 2006). In southern California, rapidly expanding populations and the formation of dense monocultures of *P. vaginatum* pose a serious threat to the structure, function, and native species composition of estuarine wetlands (Riefner & Columbus 2008).

Paspalum vaginatum, a stoloniferous and rhizomatus perennial, has been used worldwide for the rehabilitation of salt-affected lands, forage, dune stabilization and erosion control, and for turf, including specific ecotypes and cultivars with improved tolerance to saline soils (Carrow & Duncan 1998; Duncan & Carrow 1999; Duncan 2003). *Paspalum vaginatum* cultivars and ecotypes can maintain growth and vigor under irrigation with seawater, i.e., seawater is approximately EC_w (electrical conductivity of water) 54 dS/m^{-1} (deci-Siemens per meter) or ~34 ppt (parts per thousand) salt (Duncan & Carrow 1999; Lee et al. 2005; Berndt 2007; Pessarakli 2007). For comparison, freshwater habitats contain <0.5 ppt salt or <1 dS/m^{-1} (Cowardin et al. 1979); the minimum criterion required for a species to be classified as a halophyte is a salinity level having an electrical conductivity measurement of at least 7–8 dS/m^{-1} during significant portions or all of the plant's life cycle (Aronson 1989).

Although we cannot identify specific *P. vaginatum* ecotypes/cultivars that have been introduced to southern California or those growing outside of cultivation in wildlands, high-salinity tolerant plants are now established in tidal wetland habitats, including sea beaches within the high tide zone (Fig. 2a). These ecotypes/cultivars will likely disperse to other seashore habitats in the south coast region, and could possibly establish as far north as central California.

In the coastal lowland wetlands of the Hawaiian Islands, *P. vaginatum* is highly invasive in brackish wetlands (i.e., the mixohaline salinity classification [0.5–30 ppt salt] of Cowardin et al. 1979) (Bantilan-Smith et al. 2009). Although *P. vaginatum* occupies a variety of wetland and saline environments in southern California, including freshwater streams and salt marshes, preliminary salinity analysis indicates that *P. vaginatum* is highly invasive predominately in brackish wetland habitats.

As a result of continuing field documentation, unvegetated sand flats and mudflats located along tidal creeks and lagoons at the head of coastal bays and estuaries appear most vulnerable to colonization by *P. vaginatum* (Fig. 2b). Tidal mudflats are highly productive areas for invertebrates and provide rich foraging habitat for shorebirds at low tide and other birds and fish at high tide (EPA 2010). Worldwide, invasions of *P. vaginatum* are converting unvegetated or sparsely vegetated tidal flats and shallow lagoon habitats to vegetated marshland, which can displace or alter native invertebrate communities, and potentially impact foraging habitat and food resources of shorebirds (Siemens 2006; ISSG 2008; Bird Life International 2009).

Human activities such as dredging and filling have contributed to the loss of tidal mudflats in southern California (Williams & Desmond 2001). Invasions by nonnative species, however, now also pose a threat to estuarine wetland ecosystems (Grewell et al. 2007). Accordingly, development of urban watershed and estuary conservation management plans should include identification and eradication programs to deter the spread of nonnative plants, especially potentially invasive halophytes that could further degrade sensitive estuarine wetlands in southern California.

DISCUSSION

As a result of field work in southern California, and a review of pertinent literature and electronic databases such as the Consortium of California Herbaria (2010), we provide a summary of the distributional records, current naturalized status, occupied habitats, document invasive behavior, and speculate where recently introduced *Paspalum* species might become invasive. These data are summarized in Table 1. Naturalization categories shown in Table 1 are somewhat subjective, but follow Hrusa et al. (2002) in order to allow consistency in data compilation of new introductions for California, which include: naturalized in wildlands (NW); naturalized outside of wildlands, including urban and widlland-urban interface habitats (N); and persistence tenuous (TEN).

Dean et al. (2008) recently pointed out the confusion regarding identifications and the relative naturalized distributions of *Paspalum notatum* Flüggé var. *notatum* versus *P. notatum* var. *saurae* Parodi in California. Considering the ongoing difficulties with separating *P. distichum* from *P. vaginatum*, we provide the following key that will serve to identify the species and varieties of *Paspalum* known to occur in California.

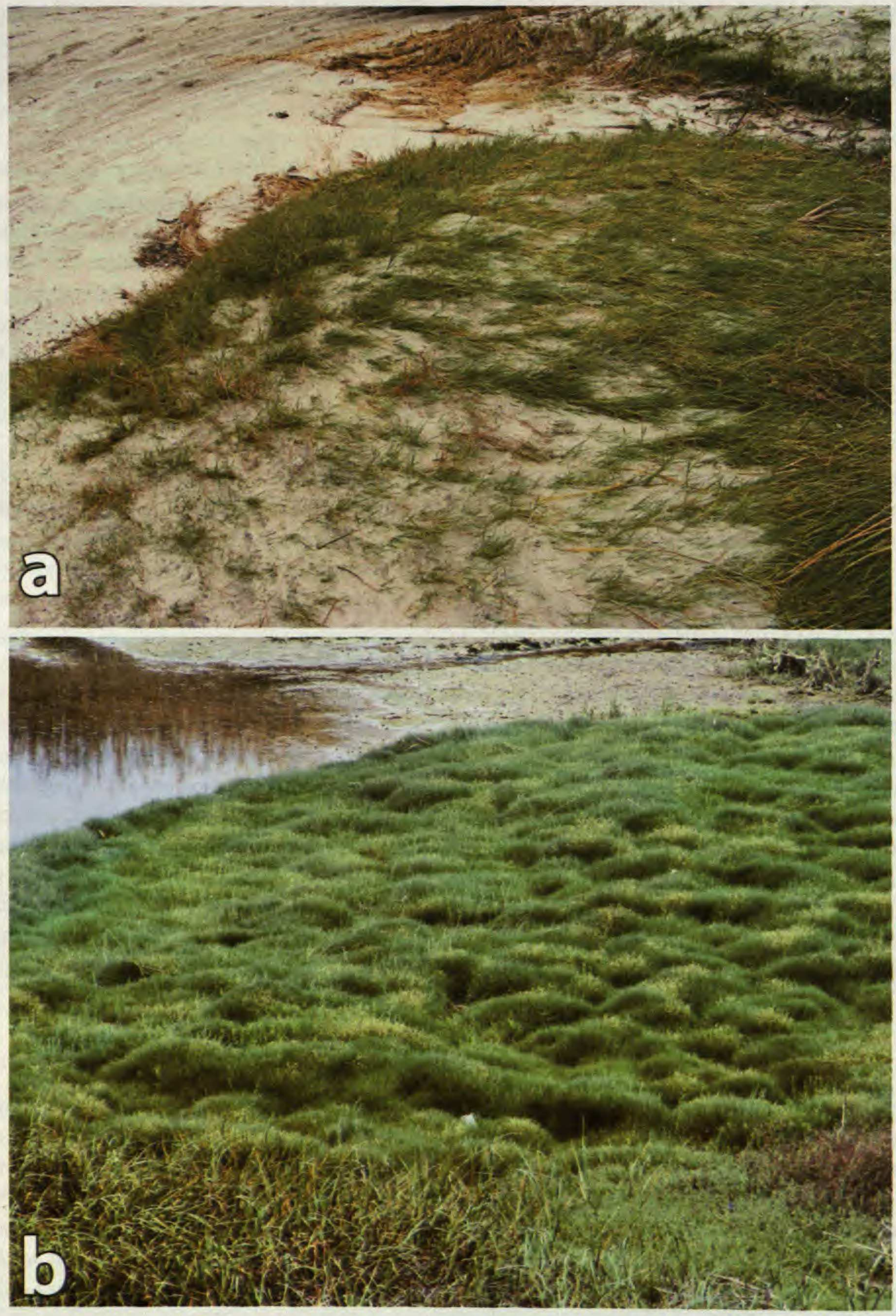

Fig. 2a. View of *Paspalum vaginatum* established on an ocean beach routinely wetted by seawater during high tide events. Photograph taken in August, 2008, Salt Creek Beach, Orange County, California.

Fig. 2b. *Paspalum vaginatum* invasions can convert tidal mudflats to an exotic-plant dominated salt marsh. *Spartina foliosa* is shown in the lower left-hand corner, which typically marks the boundary between vegetated salt marsh and unvegetated mudflat. Photograph taken in June, 2009, along San Diego Creek near its confluence with Upper Newport Bay, Orange County, California.

TABLE 1. Summary of distributional records, current naturalized status, occupied habitats, and observed or potential invasive behavior of three recently introduced *Paspalum* species in California.

Species	Significance in California	Naturalized status and habitats	Invasive behavior
P. pubiflorum	New to State; expected elsewhere in southern and central California	N–urban creek NW–river banks and shallow waters	Possibly alkaline wetlands (not estuarine wetlands) in coastal and mountain foothill regions, less likely in the Sonoran Desert region
P. quadrifarium	New to State; expected elsewhere in coastal southern California, possibly Sonoran Desert region, unlikely elsewhere	TEN–riparian scrub	Possibly riparian habitats in southern coastal regions, especially San Diego Co., and the Sonoran Desert region, unlikely elsewhere
P. vaginatum	Additional records documented for Orange, Riverside, and San Diego counties; first record documented for sea beaches within high tide zone	N–urban creeks NW–freshwater streams and wetlands, tidal creeks and lagoons, brackish and salt marshes, mudflats, coastal strand, and sea beaches	Invasive south coast region, mostly estuarine wetlands, could disperse and establish in central coastal region. Established saline wetlands in the Sonoran Desert region, invasive behavior unlikely along the Salton Sea (salinity >sea water)

A KEY TO *PASPALUM* IN CALIFORNIA

1. Spikelets entirely glabrous, solitary.
   2. Spikelets elliptic-lanceolate, 3–4.5 mm long, plants rhizomatous and stoloniferous, rachis of racemes winged; freshwater to saline wetlands, mostly estuarine habitats _____ **P. vaginatum**
   2. Spikelets broadly elliptic, ovate or obovate, 2.8–4 mm long, plants rhizomatous, rachis of racemes triquetrous to narrowly winged; moist disturbed sites and urban environments _____ **P. notatum**
      3. Spikelets 3.2–4 mm long, blades 0.4–1 cm wide; tetraploids; moist disturbed places, roadsides, turf, fields _____ var. **notatum**
      3. Spikelets 2.8–3.2 mm long, blades 0.2–0.4 cm wide; diploids; disturbed moist urban environments, lawns, gardens, roadsides _____ var. **saurae**
1. Spikelets glabrescent, pubescent, or pilose to ciliate, solitary or paired.
   4. Spikelets mostly solitary, 2.4–3.2 mm long, paired or mixed solitary and paired spikelets may be present, racemes mostly digitate, proliferating racemes may be present, upper glumes sparsely to short pubescent on back; moist to wet disturbed sites, freshwater or brackish marshes, occasionally tidal wetlands _____ **P. distichum**
   4. Spikelets paired.
      5. Inflorescence usually with 10 or more racemes present, the racemes decreasing in length towards the apex.
         6. Spikelets 1.5–3 mm long, margins of upper glumes and lower lemmas pilose to ciliate, glumes long pubescent, 10–20 (30) racemes per inflorescence; plants cespitose, tufted, with short crowded rhizomes; disturbed moist places, ditches, fields, gardens _____ **P. urvillei**
         6. Spikelets 2–2.5 mm long, margins of upper glumes and lower lemmas entire, upper glumes pubescent, lower lemmas glabrous or pubescent, 5–32 (44) racemes per inflorescence; plants cespitose, tussock-forming, generally lacking rhizomes; disturbed riparian scrub _____ **P. quadrifarium**
      5. Inflorescence usually with 2–7 racemes present, each raceme about the same length.
         7. Spikelets 2.3–4 mm long, elliptic, margins of upper glumes and lower lemmas pilose to ciliate, surfaces sparsely pilose; plants cespitose with short rhizomes; moist disturbed sites, urban environments, occasionally wetland and riparian habitats _____ **P. dilatatum**
         7. Spikelets 2.4–3.2 mm long, elliptic to obovate-elliptic, margins and surface of upper glumes and lower lemmas pubescent, rarely glabrescent or glabrous; plants decumbent, rooting at the nodes; disturbed creek and river banks, and shallow water habitats _____ **P. pubiflorum**

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